University of HUDDERSFIELD
Institute of Railway Research

International Collaborative Research Initiative Workshop

Wheel Damage Research

Dr Adam Bevan

RSSB, London, February 2017

Overview

University of HUDDERSFIELD
Institute of Railway Research

- Background
- Damage mechanisms
- Quantifying surface damage
- Modelling wheel tread damage
  - Profile shape (wear)
  - Rolling contact fatigue
- Material challenges
- Gaps and potential collaboration

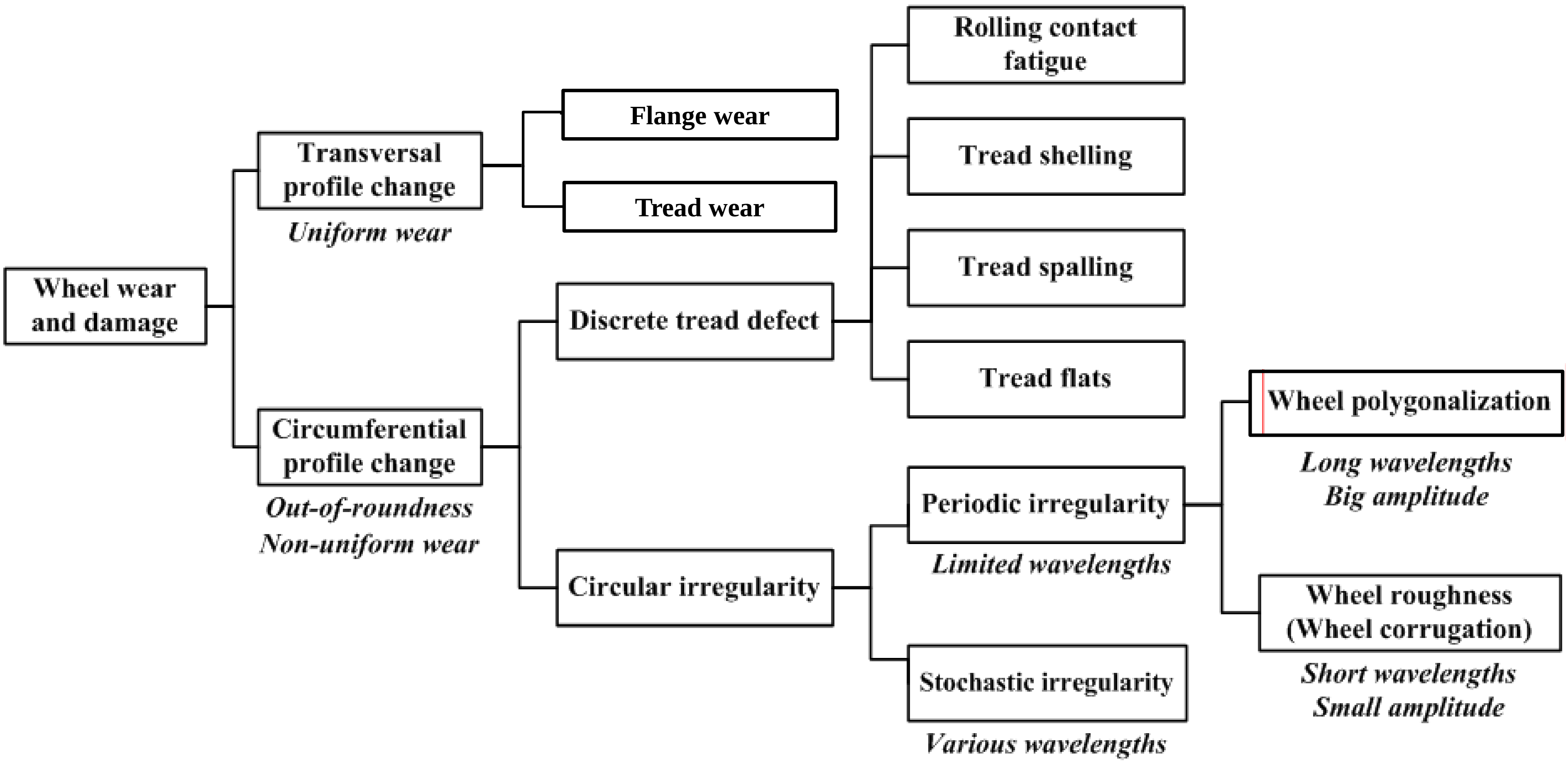
Background

University of HUDDERSFIELD
Institute of Railway Research

- Wheelsets are expensive:
  - Manufacturing
  - Reprofiling
  - Inspections
  - Renewal
  - Environmental impact
  - Costs of trains out of service
- Strong demand to reduce the rate of wheel damage
  - Extend wheel re-profiling intervals
  - Better wheelset life
  - Lower costs

Damage Mechanisms

University of HUDDERSFIELD
Institute of Railway Research



Damage Mechanisms

University of HUDDERSFIELD
Institute of Railway Research

Profile wear prediction:

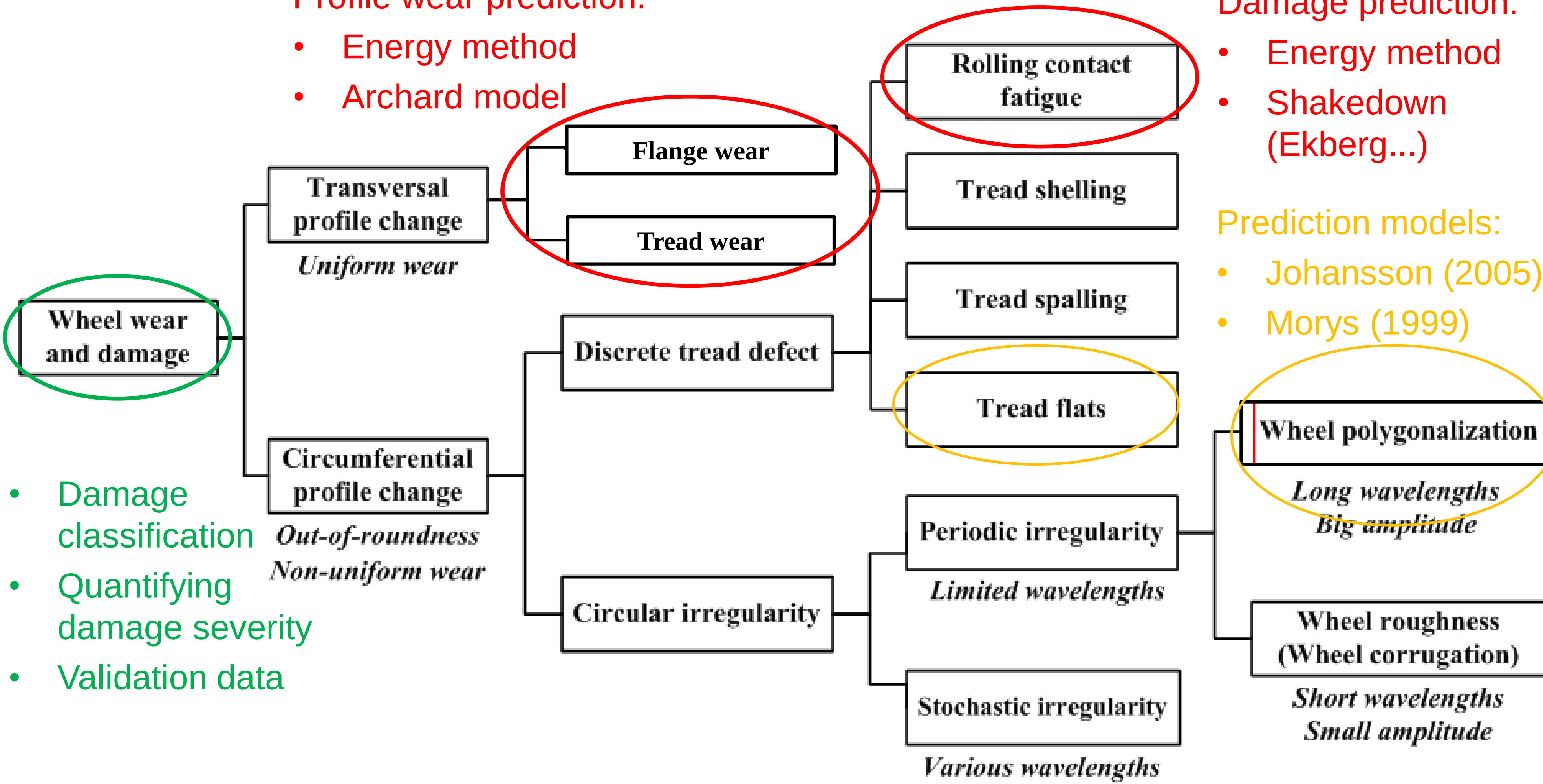
- Energy method
- Archard model

Damage prediction:

- Energy method
- Shakedown (Ekberg...)

Prediction models:

- Johansson (2005)
- Morys (1999)



- Damage classification
- Quantifying damage severity
- Validation data

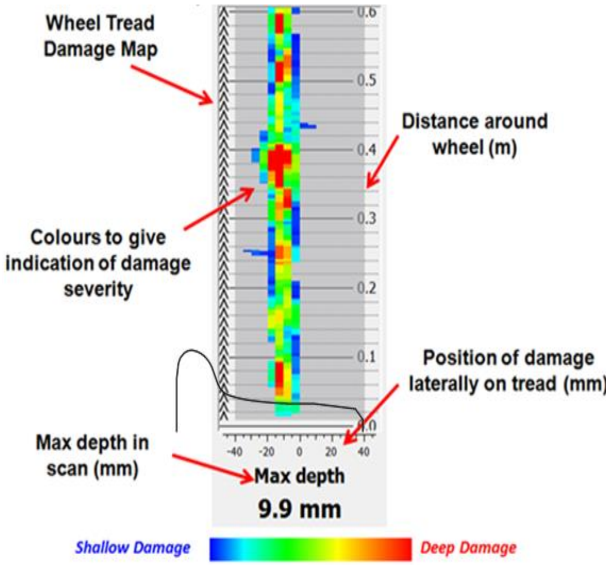
Quantifying Surface Damage (1)

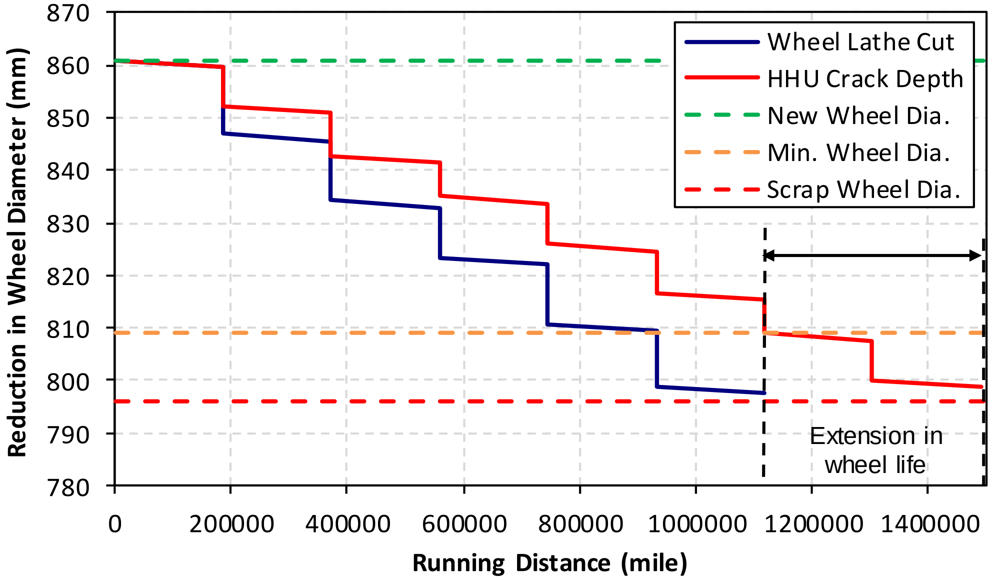
- MRX's Surface Crack Measurement (SCM) technology has been in use on rails for 8 years+
- Technology adapted to measure surface and sub-surface cracking in wheels
- Funding awarded by RSSB to further develop and validate the wheel SCM device
- Wheel SCM device reports the depth of the deepest artifact in the entire wheel scan
  - Reported depth is the amount of material to remove from the wheel to eliminate the measured damage

Bevan, A. and Klecha, S. (2016) 'Use of Magnetic Flux Techniques to Detect Wheel Tread Damage' Proceedings of the ICE - Transport , 169 (5), pp. 330-338. ISSN 0965-092X

Quantifying Surface Damage (2)

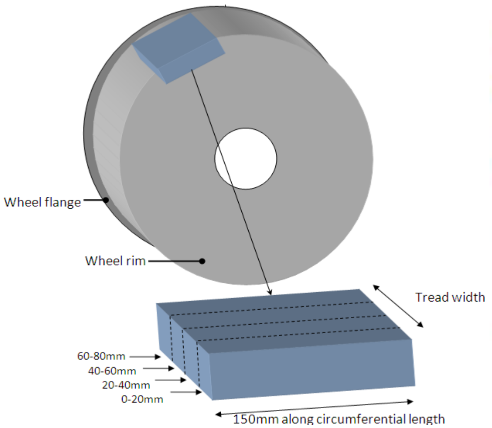
- Replacing replace visual inspection during routine maintenance exams
- Optimise wheel lathe cut depths
- Trending to understand RCF development and growth rates
- Supporting specific case studies

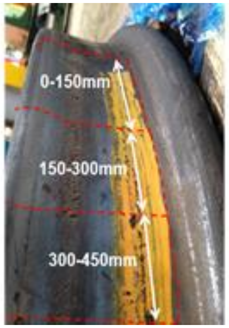


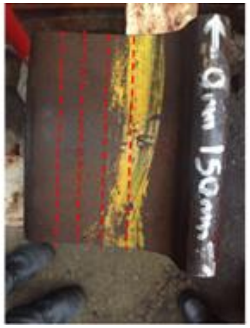


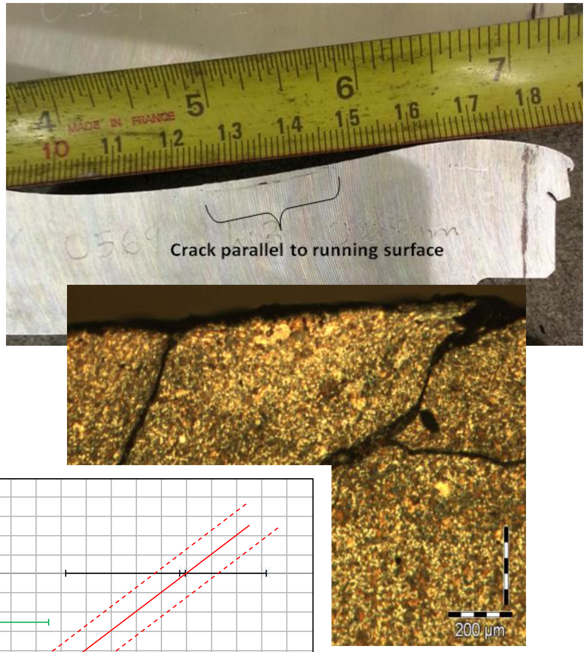
- Wheelset life tracked based on observed average wear rates and cut depths (with and without use of HHU)
- Increase in wheel life by 2 additional turning activities (~370kmi) and saving in wheelset costs of ~25%

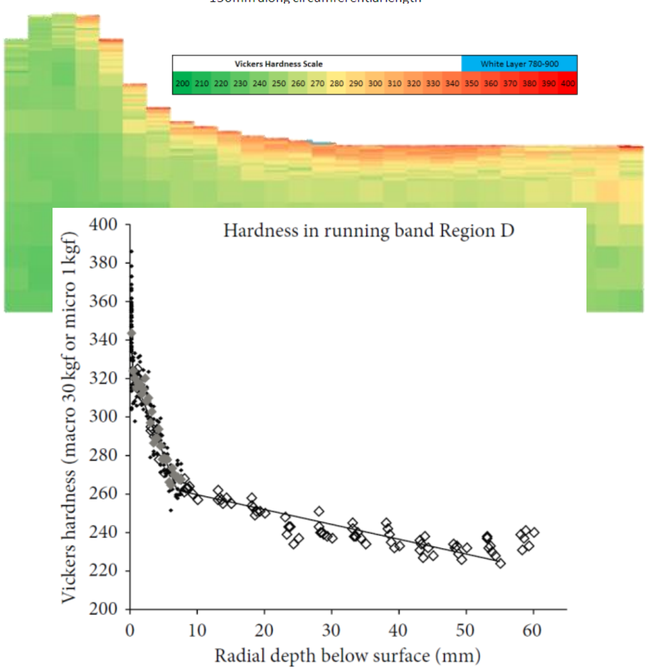
Wheel Sectioning and Examination

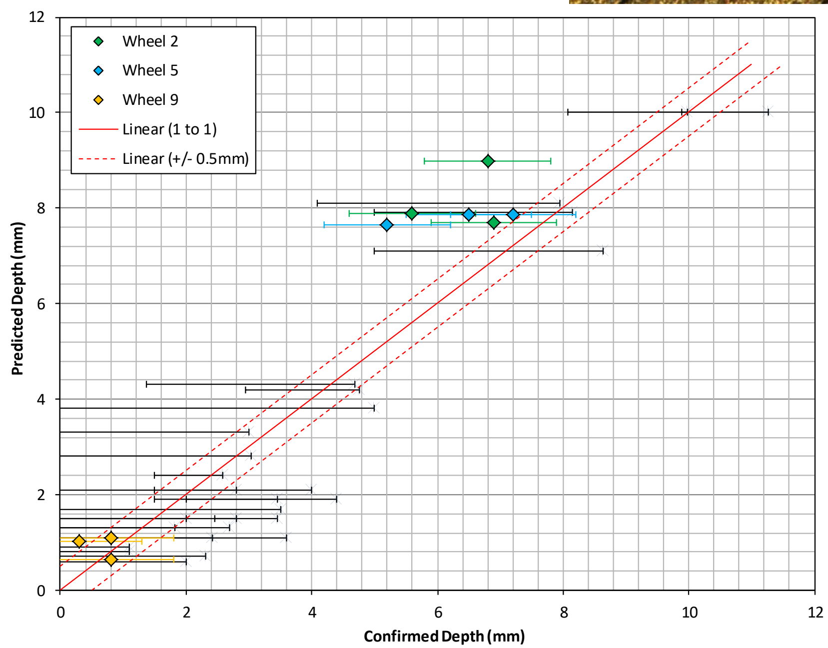












Classification of Damage

University of Huddersfield
Institute of Railway Research

- Categorisation of wheel damage mechanisms to improve identification and selection of appropriate mitigation


RSSB

T963 Wheel Tread Damage Guide

Foreword

It is with the greatest of pleasure that I introduce this Wheel Tread Damage Guide. Every train that I have ever seen has wheels. We all spend hours and significant sums of money maintaining and repairing them. But what is the best way for us to do this today and how can we diagnose the cause when something goes wrong with our wheels? This Wheel Tread Damage Guide sets out to answer these questions, to share best practice and work out the steps we can take as maintainers, train builders, owners and operators to maximise wheelset life and ultimately save money.

This text has been produced to address the needs of everyone involved in managing wheels. It has been created from studying the influence of train architecture, route conditions and maintenance practises on wheel tread damage and establishes a common basis for

As the Project Champion I am deligh
Committee sponsorship has allowed

Most important of all, we want to ext
without which this would not have be
photographs or evidence of new whe

Project Champion

Simon Jarrett

Engineering Manager

Chiltern Railways

RSSB

2.19 RCF Clusters

Rolling contact fatigue clusters are a particular localised damage effect which can occur in the centre of the wheel tread. This part of the wheel experiences the largest number of stress cycles, but with limited tangential forces the highest stresses may be below the surface. They are rarely a fleet-wide problem.

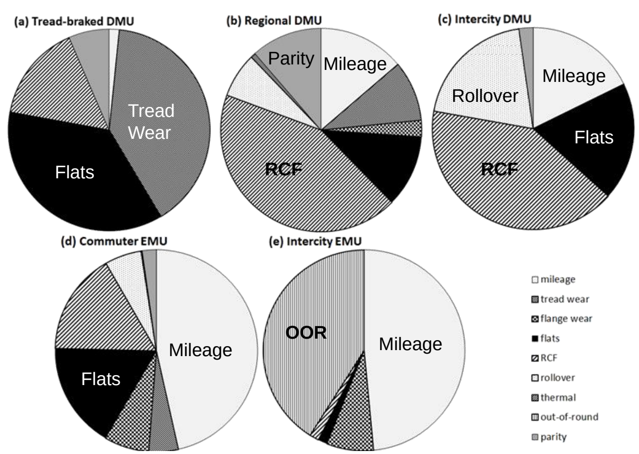
2.19.1 *Damage Mechanism*

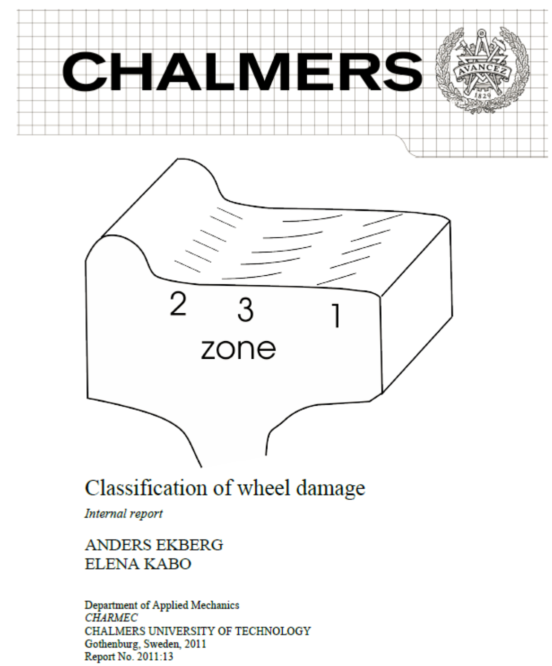
The localised phenomenon of RCF Cluster cracks are often initiated sub-surface, and may be associated with inclusions or other localised material defects. Rolling contact fatigue cluster crack networks are also associated with local plastic material deformation and ratchetting in common with conventional RCF. When turning a wheel on the lathe with no apparent surface damage, the initial sub-surface stage of RCF cluster damage may become apparent after the first cut. Observations of rolling contact fatigue clusters are often associated with a localised hollow tread or a local radial run-out effect.

Once established, such cluster crack networks propagate at a significant rate and when the developed crack network spreads on the surface it can lead to localised shelling of the wheel tread. This can become severe even after a limited mileage has elapsed, because the out-of-round effect causes high impact forces which accelerate the crack propagation.

(a) (b) (c) (d)

Figure 2.25: (a), (b) Localised clusters of surface cracks or cavities may indicate RCF clusters, (c), (d) Cracks may appear larger, more widespread or more visible during turning



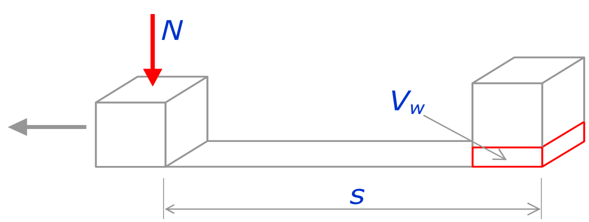


Bevan, A., and Molyneux-Berry, P., Improving Wheelset Life by Better Understanding the Causes of Wheel Damage, Summary Report, RSSB project T963, 2013

Profile Wear Prediction

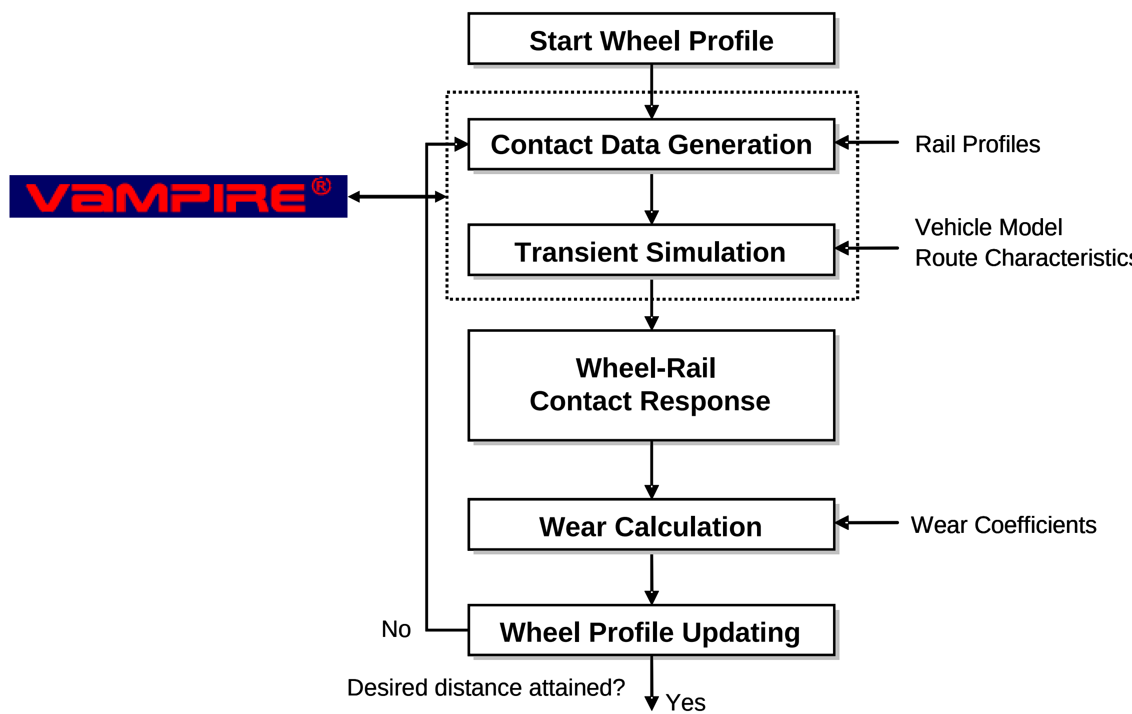
University of HUDDERSFIELD
Institute of Railway Research

- Utilises the wear iteration procedure developed by KTH (Sweden) and applied to GB rolling stock by MMU/UoH
- Wear calculation based on Archard wear model
  - Volume of material removed predicted based on the normal force, tangential forces, creepages and material properties



$$V_w = k \cdot \frac{N \cdot s}{H}$$

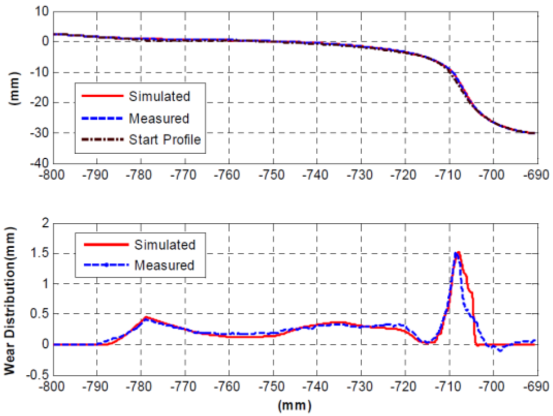
V_w = Volume of wear
s = Sliding distance
N = Normal force
H = Hardness
k = Wear coefficient

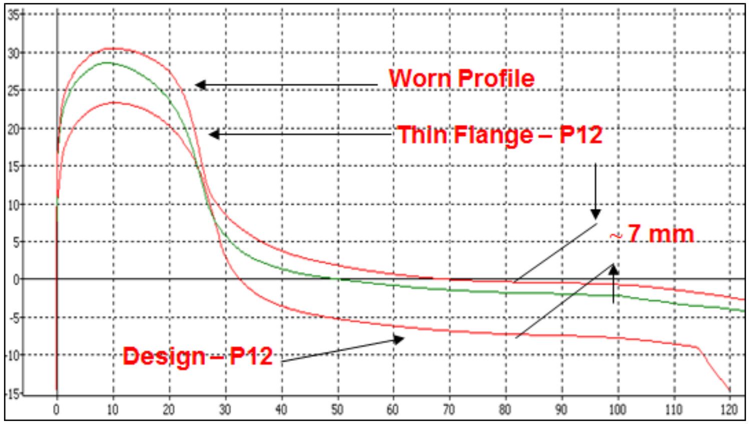


Example Applications

University of HUDDERSFIELD
Institute of Railway Research

- Development of P12 (anti-RCF) wheel profile
- Assessment of economic tyre turning
- Modified P8 wheel profile
- Wheel profile wear limits (GM/RT2466)



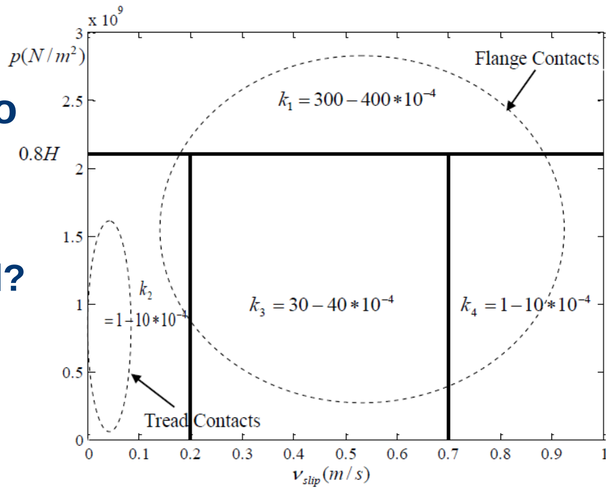


Bevan, A. and Allen, P. (2006) 'Application of a wear prediction method to the analysis of a new UK wheel profile'. In: Proceedings of the 7th Contact Mechanics and Wear of Rail/Wheel Systems Conference, 24th-27th September 2006, Brisbane, Australia

Areas of Development

University of HUDDERSFIELD
Institute of Railway Research

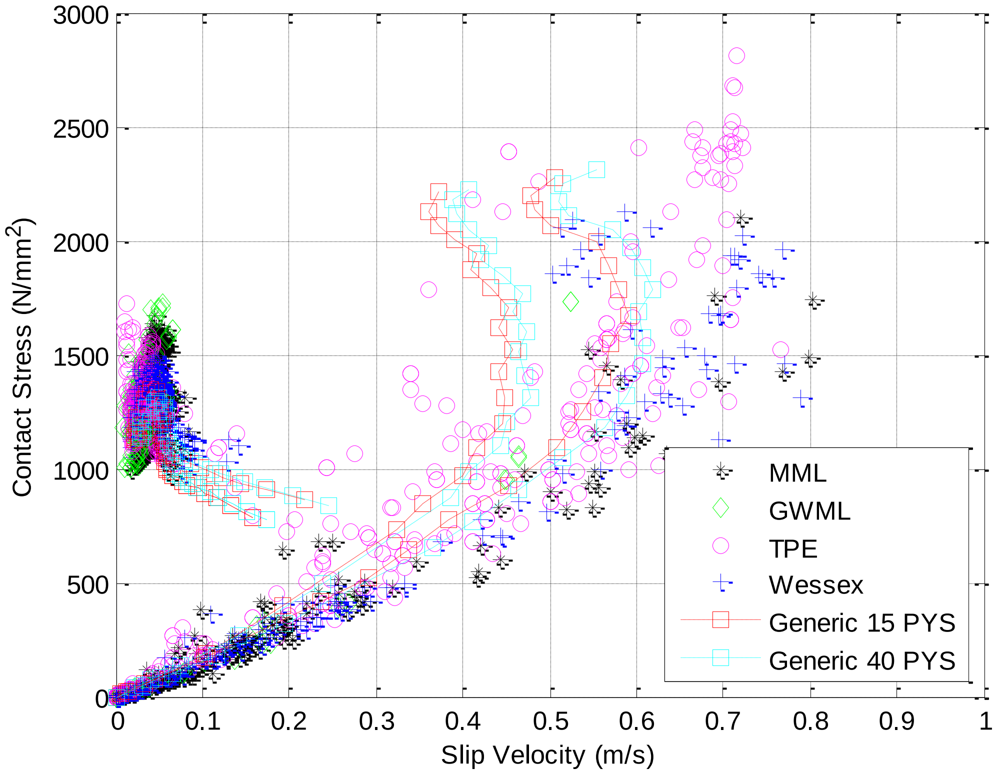
- Most fleets operate on a wide range of routes with large total mileage and varying conditions (e.g. curve radii, cant deficiency, rail profile, traction/braking forces and lubrication)
- Two modelling approaches developed:
    1. *Route-based* – running an analysis over long distances including the full range of conditions can take considerable time
    2. *Vehicle duty-cycle* – routines developed to represent the duty-cycle of the vehicle with a series of much shorter simulations
- **What are the most influential factors and how detailed do the simulations need to be to capture these differences?**
- **Applicability of current wear coefficients:**
    - **Representative of the range of conditions seen by the wheel?**
    - **Representative of different route characteristics and environmental conditions?**
- **Influence of wheel-rail contact model**



Wear Coefficients (1)

University of HUDDERSFIELD Institute of Railway Research

- Contact stress vs. Slip velocity

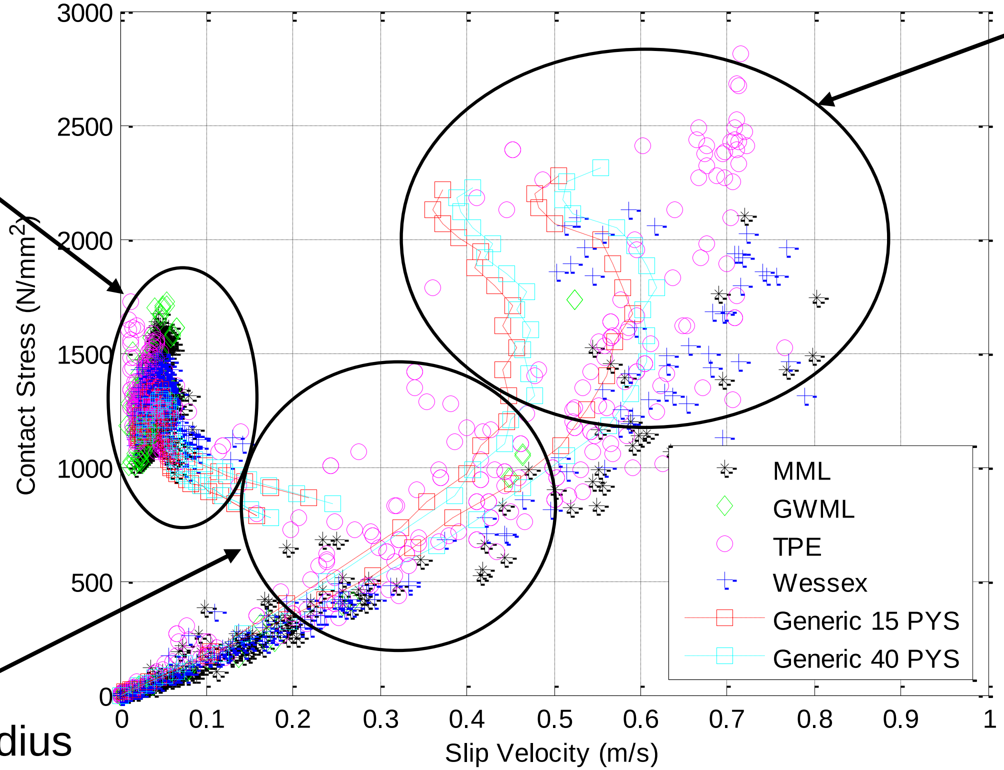


Wear Coefficients (2)

University of HUDDERSFIELD
Institute of Railway Research

- Contact stress vs. Slip velocity

- Shallow radius curves
- Single-point contact tread



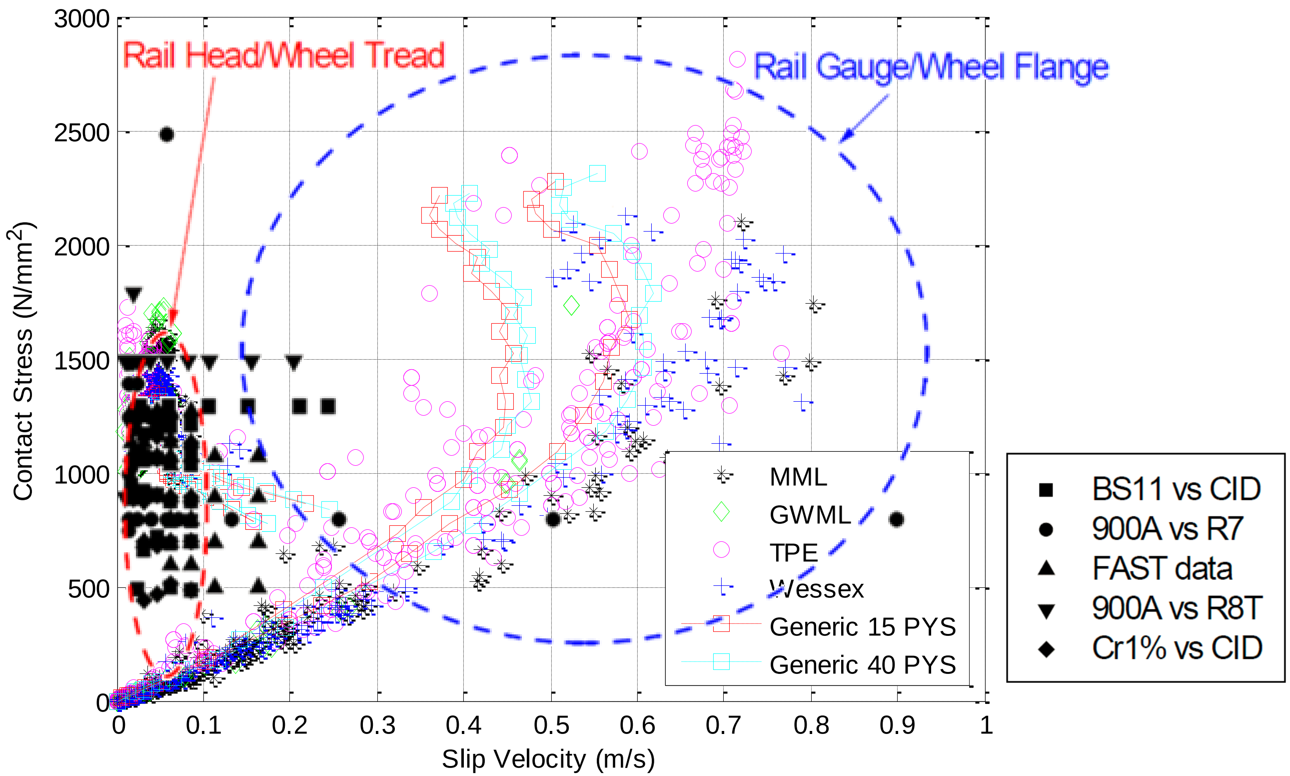
- Small radius curves
- Single-point flange contact

- Medium radius curves
- Two-point contact

Wear Coefficients (3)

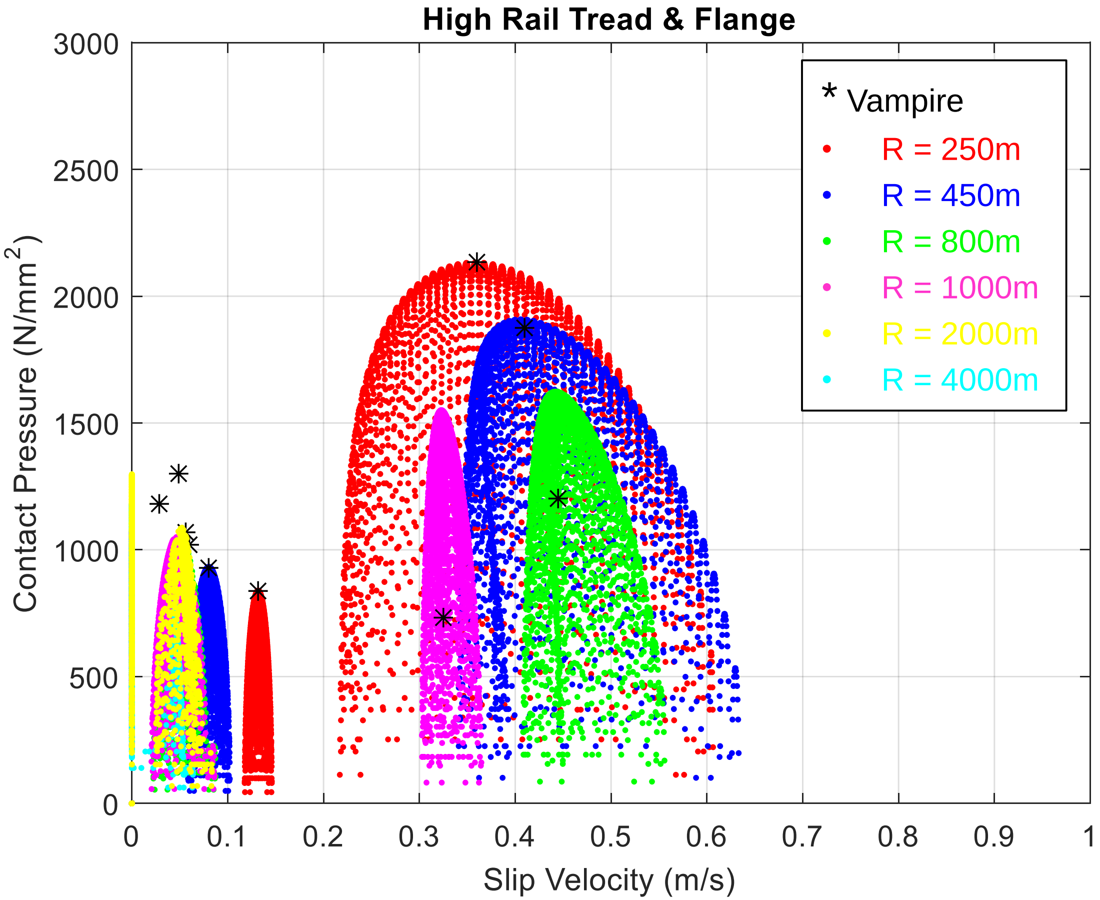
University of HUDDERSFIELD Institute of Railway Research

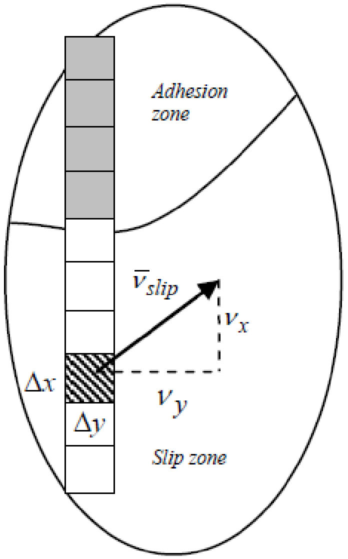
- Contact stress vs. Slip velocity



W-R Contact Modelling

- FASTSIM incorporated in wear modelling

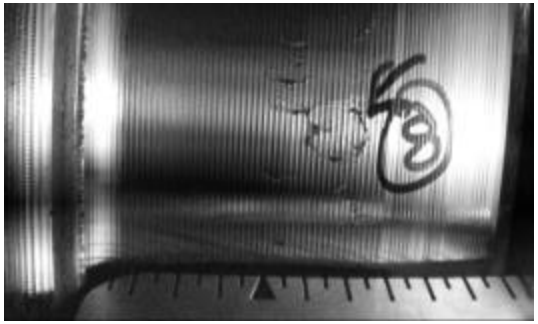




RCF Cracks in Wheels (1)

University of Huddersfield
Institute of Railway Research

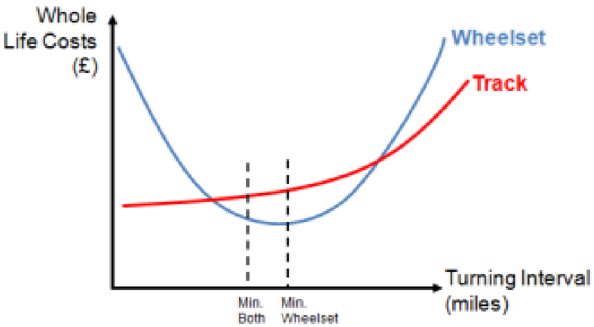
- Railway wheels operate in a demanding environment
  - High normal contact forces
  - Significant tangential forces (traction, braking, curving)
  - Contaminants (water, sand, leaves etc)
- Stresses exceed yield stress of the as-manufactured material
  - Plastic flow, wear and fatigue damage
- Rolling contact fatigue is a dominant damage mechanism
  - Many fleets have their wheels turned on a preventive distance-interval
  - ‘State of the art’ modelling of RCF in railway wheels has not achieved a deterministic model owing to the complexity of the conditions



RCF Cracks in Wheels (2)

University of HUDDERSFIELD
Institute of Railway Research

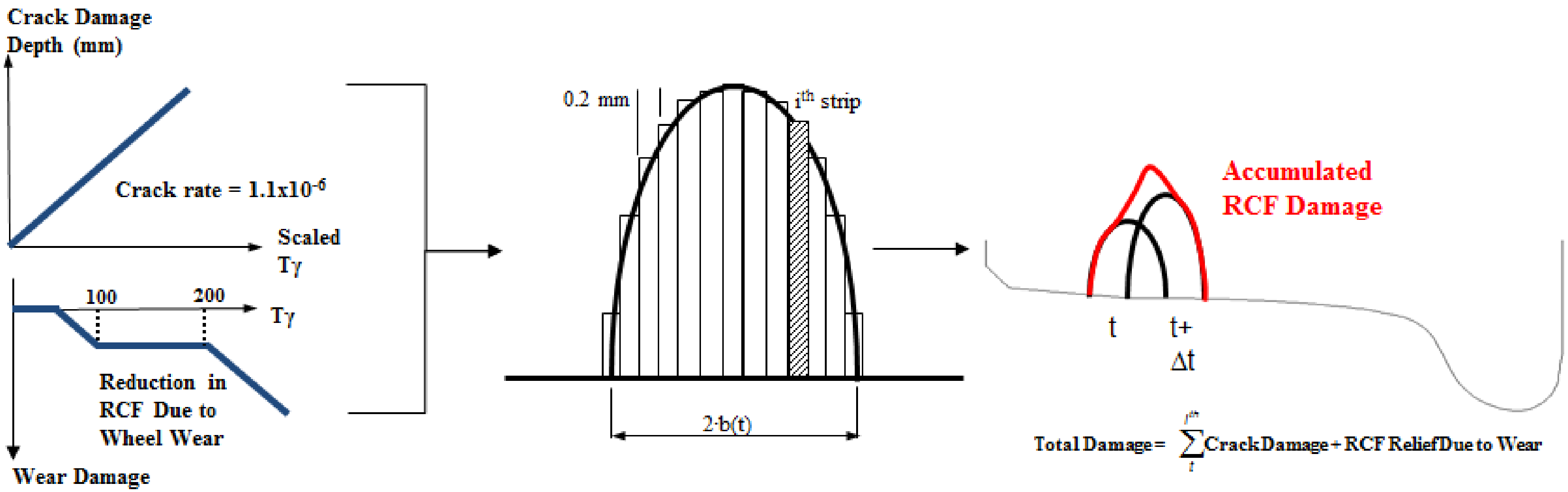
- Many factors influence RCF crack growth rates in wheels:
  - Material properties
  - Train/wheelset type
  - Operating/environmental conditions
  - Position of wheelset on train
  - Distance run since last tyre turning
- RCF growth rate is higher as the wheels near the end of their life
  - Approaching the minimum diameter before the wheelset is renewed



Wheel RCF Prediction

University of HUDDERSFIELD
Institute of Railway Research

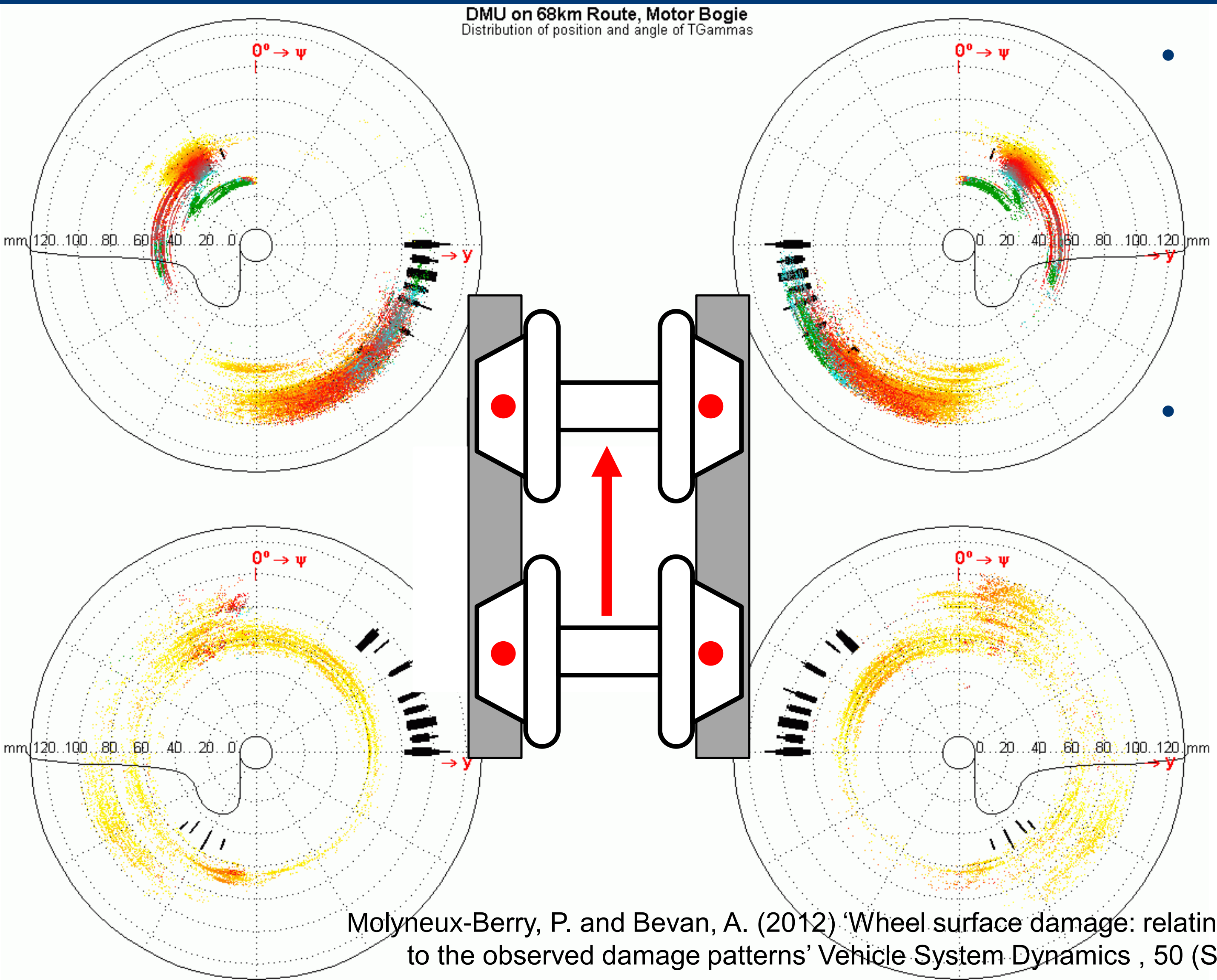
- Methodology:
  - Read outputs from vehicle dynamics simulations
  - Scale Tγ based on the direction of the longitudinal force (RCF damage only occurs when the wheel is the driven surface)
  - Calculate crack damage using scaled Tγ and wear damage using un-scaled Tγ
  - Calculate total damage (crack + wear damage)
  - Distribute damage elliptically over the width of the contact patch
  - Accumulate damage and weight to represent vehicle operating conditions



Bevan, A., Molyneux-Berry, P., Eickhoff, B. and Burstow, M. (2013) ‘Development and Validation of a Wheel Wear and Rolling Contact Fatigue Damage Model’ Wear , 307 (1-2), pp. 100-111. ISSN 0043-1648

Correlation of W-R Forces (1)

University of HUDDERSFIELD
Institute of Railway Research

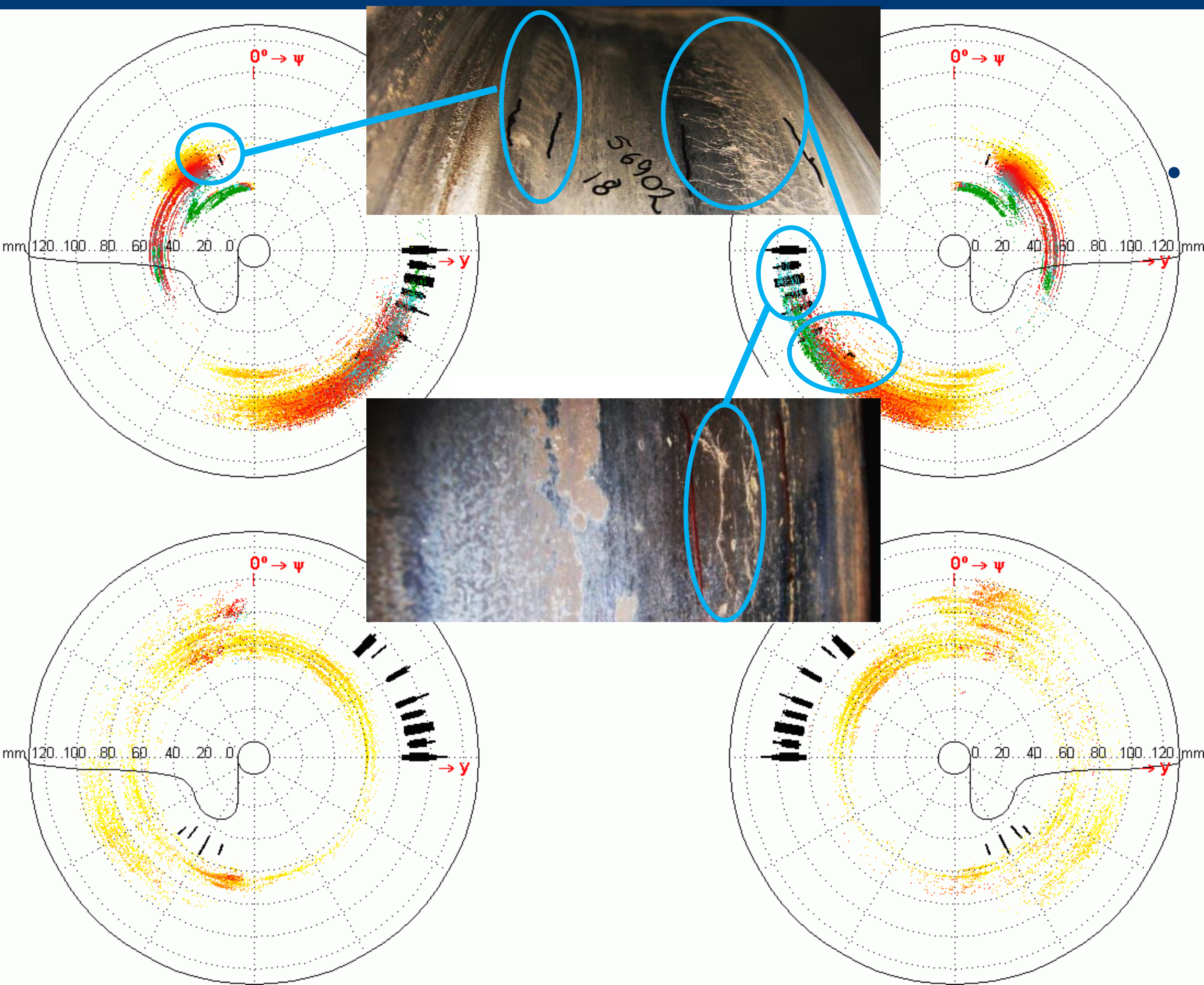


- Clear pattern of predicted forces:
  - Wide variety of input conditions
  - Damaging Tγ values are clustered in distinct areas
- Two groups of observed cracks:
  - Field side cracks 90º<|Ψ|<120º
  - Flange root cracks |Ψ|≈45º
  - Cracks plotted on all wheels of the bogie - locations mirrored as observed

Molyneux-Berry, P. and Bevan, A. (2012) 'Wheel surface damage: relating the position and angle of forces to the observed damage patterns' Vehicle System Dynamics , 50 (S1), pp. 335-347. ISSN 0042-3114

Correlation of W-R Forces (2)

University of HUDDERSFIELD
Institute of Railway Research



- Comparison of observations and predictions:
  - Crack position and angle correlate with damaging forces on leading wheelset.
  - Trailing wheelset forces are lower, no match to crack position or angle
  - Cracks correlate with the areas of higher forces (75< Tγ <175)

Accumulated RCF Damage

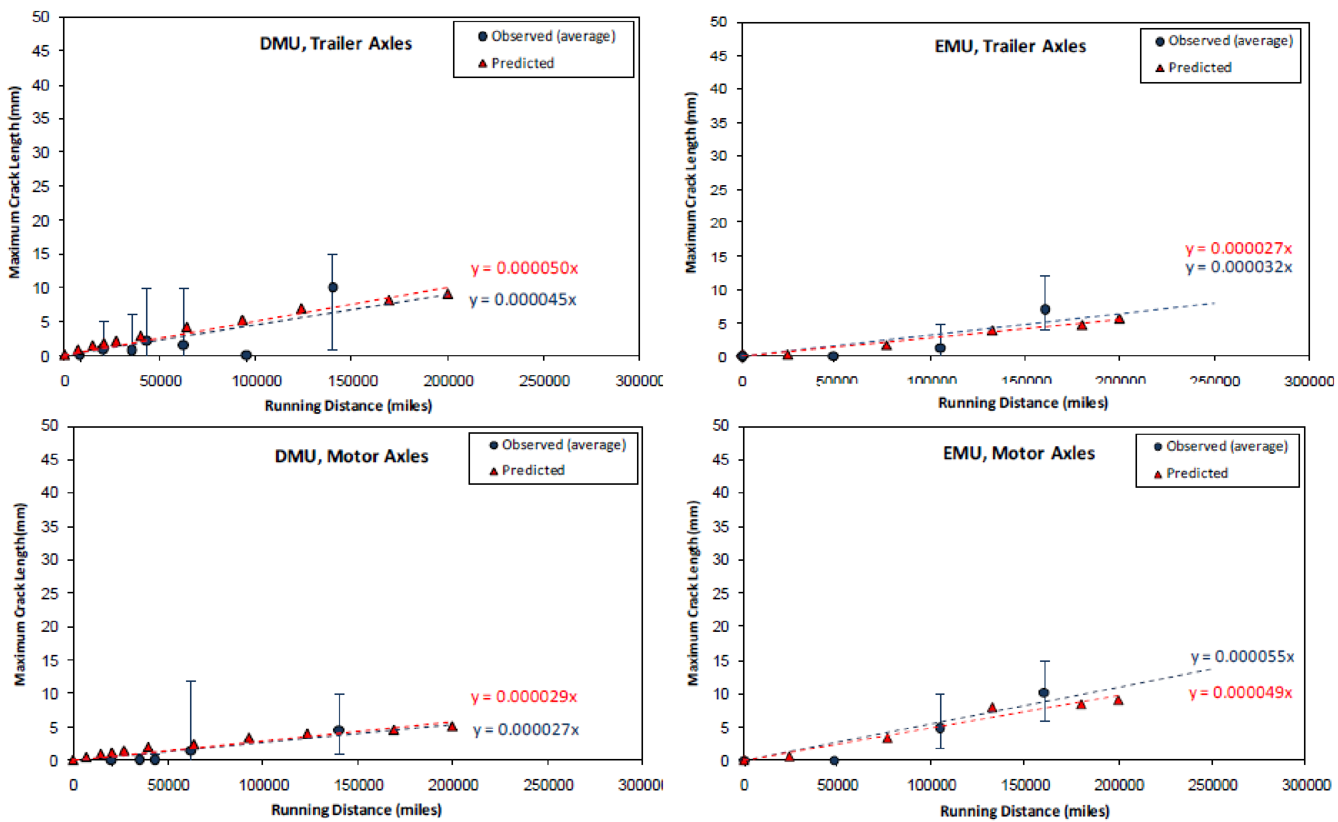
University of HUDDERSFIELD
Institute of Railway Research

- Linear regression fitted to both the observed and predicted crack lengths and damage rates determined

Diesel Multiple Unit *Electric Multiple Unit*

Trailer Axle

Motor Axle



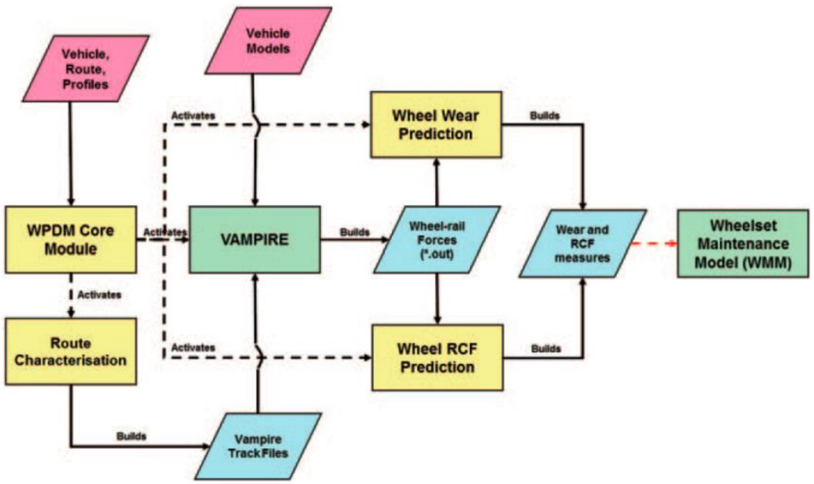
Generally a good agreement between predicted and observed damage rates is obtained

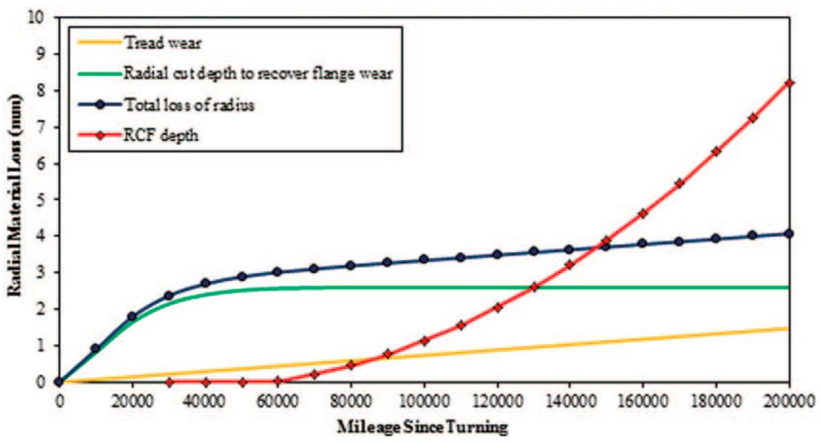
Relative damage rates between different vehicle types/axles also predicted

Example Applications

University of HUDDERSFIELD
Institute of Railway Research

- Incorporated into the Wheelset Management Model (part of the VTISM software tool)
- Optimisation of wheelset maintenance
- Assessment of economic tyre turning and modified P8 wheel profile



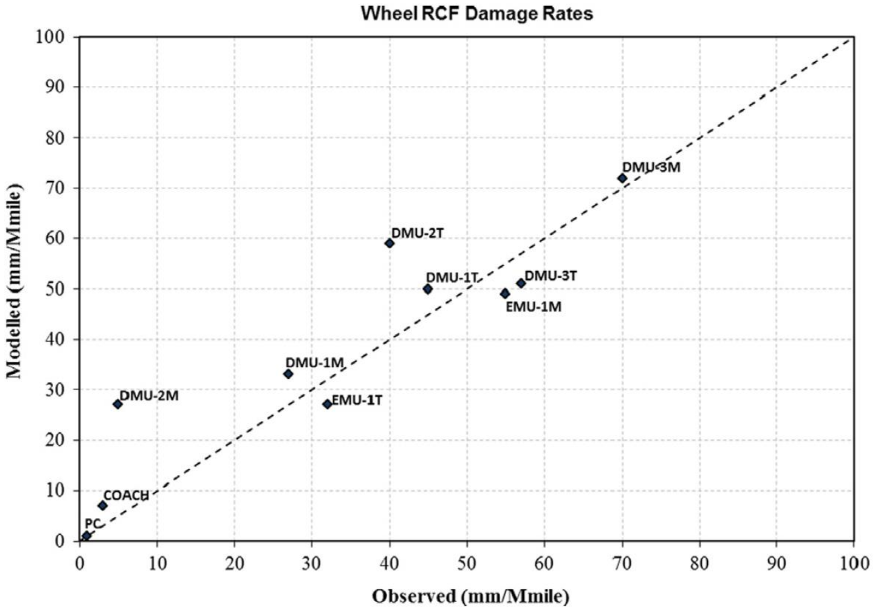


Bevan, A., Molyneux-Berry, P., Mills, S., Rhodes, A. and Ling, D. (2013) 'Optimisation of Wheelset Maintenance using Whole System Cost Modelling' Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit . ISSN 0954-4097

Areas of Development

University of HUDDERSFIELD
Institute of Railway Research

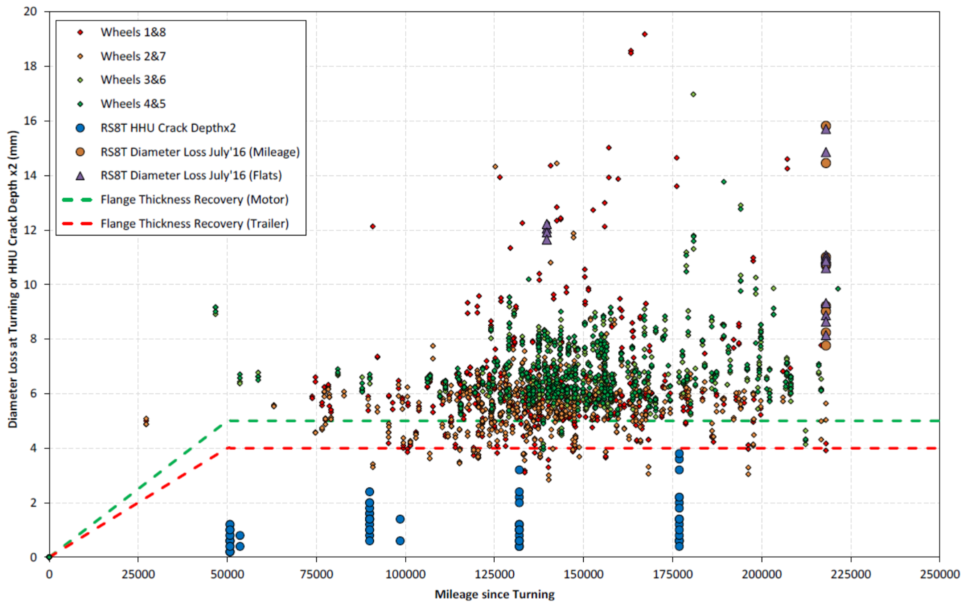
- Further validation of predicted RCF damage using measured crack depths (using NDT techniques)
  - Previous validation based on material removal at wheel lathe
- Incorporate alternative wheel-rail contact models
- Comparison with other damage models
- Influence of material properties on damage modelling



Materials Challenges

University of HUDDERSFIELD
Institute of Railway Research

- Novel wheel steels which are more resistant to wear, damage and noise (e.g. comparison R8T vs. RS8T)
- Advanced (or additive) manufacturing techniques
- Smart materials for condition monitoring
- Reduction in wheel size and mass (unsprung mass)

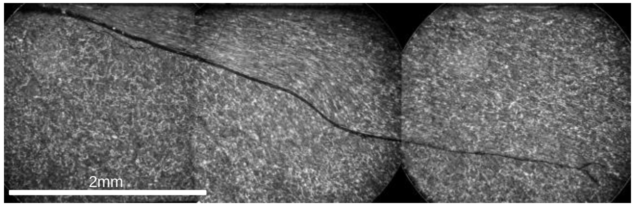


Gaps in Knowledge

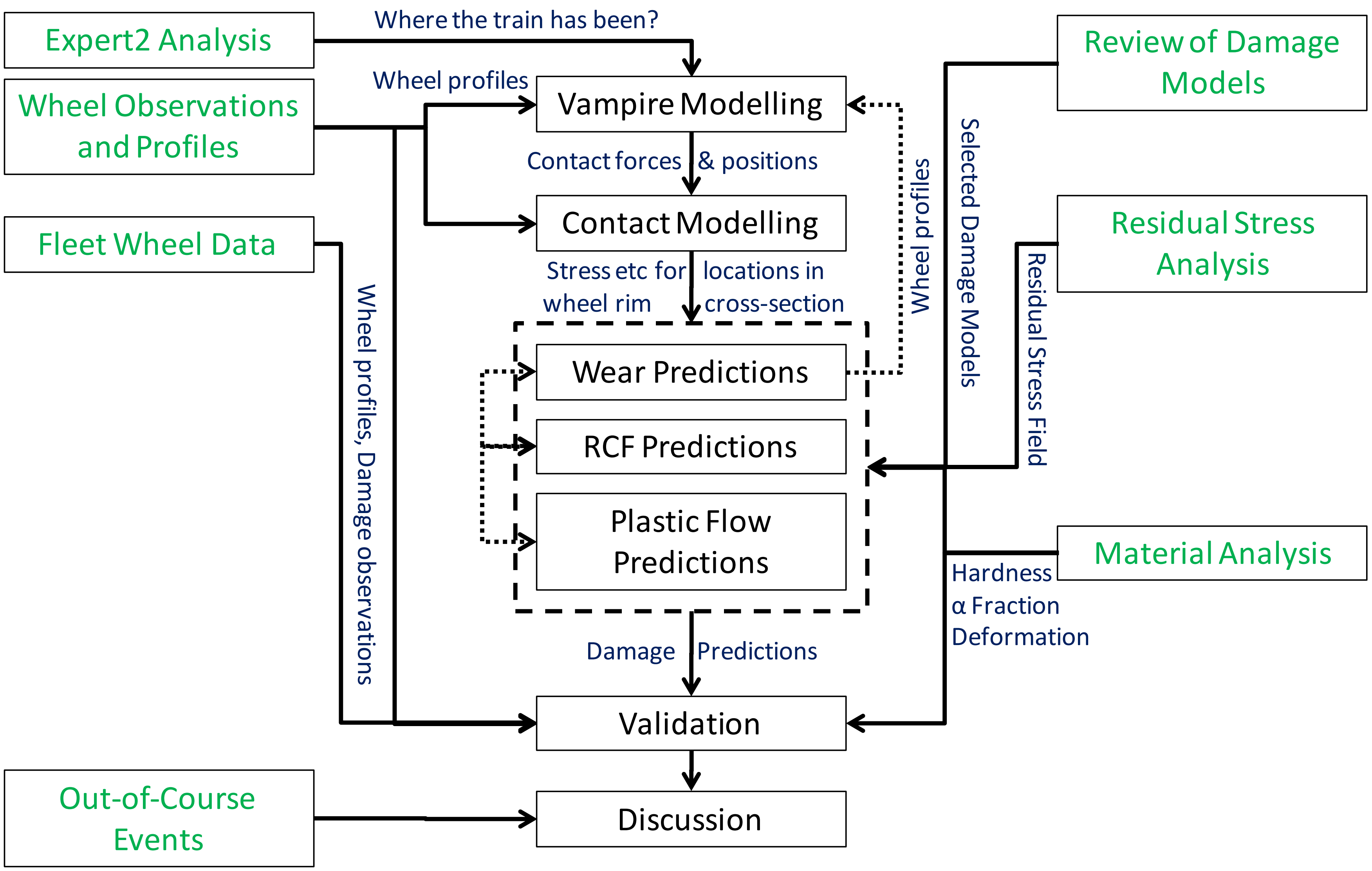
University of HUDDERSFIELD
Institute of Railway Research

- Improve fundamental understanding of wheel damage mechanisms
  - Root causes and mitigation measures
- Harmonised classification of wheel damage and maintenance statistics
  - Some work has been done in UK to improve the classification of different types of damage
  - Further work is required to quantifying the severity of damage and therefore the corrective action which should be taken
- Develop improved engineering models to aid design and optimisations
- Guidance on future design criteria and troubleshooting to reduce wheel damage related problems
- Intelligent wheelset maintenance
  - Use of data from current RCM tools (e.g. WILD, HABD….)
  - Fault diagnosis and predictive maintenance
  - Improved maintenance scheduling and planning



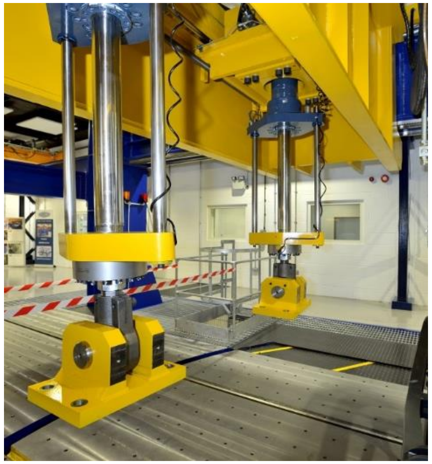


Damage Modelling



Full Scale Testing

University of
HUDDERSFIELD
Institute of Railway Research



University of Huddersfield Institute of Railway Research

Thank You